ψ Suppression in Pb+Pb Collisions: A New Look at Hadrons vs. Plasma*

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The agreement of the NA50 Pb+Pb data [1] with naive comover models is reassessed. The ψ/DY ratio as a function of E_T is

$$\frac{B\sigma_\psi}{\sigma_{\mu\mu}} = \frac{B\sigma_\psi^{pp} \int d^2b d^2s T_A^{\rm eff} T_B^{\rm eff} S_{AB}(b,s) p(E_T;b)}{\sigma_{\mu\mu}^{pp} \int d^2b d^2s T_A T_B p(E_T;b)} .$$

The ψ, ψ' and χ_c are assumed to interact with nucleons while in $|c\overline{c}g\rangle$ color octet states. The common survival probabilities for $|c\overline{c}g\rangle$ nucleon interactions are given by $T_A^{\rm eff}$ and $T_B^{\rm eff}$. Because the final charmonium state has formed by the time it interacts with comovers, the $\sim 30\%$ χ_c and $\sim 12\%$ ψ' decay contributions to ψ production are considered separately. The comvoer survival probability S_{AB} is then $S_{AB}(b,s) = 0.58\, S_\psi^{\rm co}(b,s) + 0.3\, S_{\chi_c}^{\rm co}(b,s) + 0.12\, S_{\psi'}^{\rm co}(b,s)$ where

$$S_\psi^{\rm co}(b,s) = \exp\left\{ -\langle \sigma_{\psi {\rm co}} v\rangle a n_{AB}(b,s) \ln\left(\frac{\tau_I(b)}{\tau_0(b)}\right)\right\}$$

depends on the participant density. Agreement with the data is found for $\sigma_{\psi N} = 4.8$ mb with $\sigma_{\psi{\rm co}} \approx 2\sigma_{\psi N}/3 = 3.2$ mb $\sigma_{\psi'{\rm co}} \approx 3.8\sigma_{\psi{\rm co}}$, $\sigma_{\chi_c{\rm co}} \approx 2.4\sigma_{\psi{\rm co}}$, and $a = 0.21$ in S+U collisions. However, the Pb+Pb result now disagrees with the data. The major difference lies in the normalization of the ψ/DY ratio to the pp ratio in the NA50 phase space. The angular adjustment to $|\cos\theta_{\rm CS}| < 0.5$ was left out of the Pb+Pb calculation, resulting in a 23% lower normalization in [2]. The results now suggest that the suppression is inconsistent with the assumption of the same maximum comover density in S+U and Pb+Pb interactions [2].

In light of this conclusion, color screening effects are investigated. The quarkonium potential is expected to be modified at finite temperatures by the screening mass $\mu(T)$ [3]. We assume that $\mu^2(T) = (6+n_f)\,g^2(T)T^2/6$ where $g^2(T) = 48\pi^2/[(33-2n_f)\ln F^2]$ with $F = K(T/T_c)(T_c/\Lambda_{\overline{MS}})$ [4]. A fit to the heavy quark potential at high temperatures yields $K \approx 33.8$. If the SU(3) value of K is applicable when $n_f > 0$, then the χ_c and ψ' break up while the ψ itself would not. We also use a fit to lattice results for $T \geq T_c$ which gives lower values of K, suggesting the χ_c, ψ' and ψ break up at T_c. Thus, the ψ/DY ratio could exhibit one or two thresholds as a function of E_T. We choose three illustrative cases: I) $n_f = 3$, sequential χ_c and ψ' break up; II) $n_f = 4$, χ_c and ψ' break up at T_c; and III) all charmonium states break up at T_c. Cases I and II assume $K \approx 33.8$ while case III takes K from the fit for $T \geq T_c$.

We assume $R = R_{\rm Pb}$ and $p_T \approx 0$. Realistic models do not show sharp thresholds due to the finite size of the system and fluctuations of E_T and b. A sudden change of slope, not predicted by hadronic models, appears when the plasma suppression begins, even without the assumption of total suppression. Cases I and II are in reasonable agreement with [1] but case III overpredicts the suppression. With $R = 1$ fm, case III is comparable to cases I and II with $R = R_{\rm Pb}$ when $p_T \approx 3$ GeV, somewhat higher than measured at the SPS, perhaps suggesting that only the χ_c and ψ' are suppressed.

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